

# THE 90<sup>th</sup> TEXTILE INSTITUTE WORLD CONFERENCE

Textiles: Inseparable from the human environment

25-28 April 2016

Poznan, Poland

## COMFORT PROPERTIES FOR DIFFERENT TEXTILE SETS USING A THERMAL MANIKIN

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### ABSTRACT

Textile and environmental ergonomics research have been fundamental to increase knowledge and to allow the development of specific materials, with characteristics that enable them to create effective barriers between the human body and the environment.

Thermal manikins are important tools whose use over the years have allowed for rigorous and safe thermal testing of clothing, thus enhancing our understanding of the thermal properties of the tested materials. Moreover, these manikins allow researchers to study body temperature characteristics in neutral or cold environmental conditions, at low levels of activity.

For the person undergoing surgery, the operating room presents itself as an extreme thermal exposure context. Therefore, it is important to care for the patient's thermal body protection

With this in mind, different textile sets, intended to be used in the operating room, were designed and tested on a thermal manikin.

**Keywords:** Thermal manikin, Thermal insulation, Thermal comfort, Perioperative warming

### INTRODUCTION

Human life depends on the body's ability to maintain its own internal temperature at around 37 °C. Clothing has always been used as an aid to this internal mechanism, since it reduces the amount of heat leaving the body to the environment, and thus helps keep body temperature within vital parameters.

Textile and environmental ergonomics research has been fundamental to increase knowledge and allow for the development of materials with specific purposes.

Thermal manikins were created originally to test uniforms and clothing for the US Army's use (Holmér, 2004). They are important tools that have been applied to research in these and many other areas.

Their use over the years has allowed for the rigorous and safe thermal testing of clothing, and thus has increased understanding of the thermal properties of different tested materials. Moreover, they also provide information about the mechanisms of heat transfer between the human body and the environment (Holmér, 2004 and Abreu, 2008).

With the configuration of an adult human body and divided into thermally independent segments, these models can be constructed in different materials, but they are all able to reproduce in the laboratory some physiological processes of interaction between the human body and the environment. They also accurately simulate the human reaction to the thermal environment (Holmér, 2004, Abreu, 2008 and Pamuk, Abreu & Öndoğan, 2008). Due to their characteristics, for example, thermal manikins allow researchers to study the body temperature characteristics in neutral or cold conditions, at low levels of activity (Holmér, 2004).

Due to their homeothermic ability, humans are able to protect themselves from environmental hostility through internal mechanisms activated by cold or heat. These mechanisms involve biochemical reactions – to promote a rewarding thermoregulation - and behaviors that stimulate the actions of self-protection, such as a search for food or shelter.

In thermally adverse situations or with body fragility, as is the case of the person in a diseased condition, both mechanisms are impaired and the person runs the risk of becoming hypothermic.

Preventing hypothermia and promoting the comfort of the person with surgical needs is one of the priorities of health professionals in the perioperative setting, because they understand the fragile condition of the patient, and the severity of the environmental conditions. Before surgery, the individual condition of patients is poor due to biochemical changes caused by anxiety, fasting, and limited clothing. These elements, associated with the low room temperature and the large air movement caused by air conditioning inside the operating theater, increase the temperature drop and the thermal discomfort sensation. In order to improve the thermal body protection of the upper body of persons undergoing surgery in the lower body, different textile sets were developed and tested using a thermal manikin.

## **MATERIALS AND EXPERIMENTAL METHODS**

All tests were performed in the Textile Engineering Laboratory at the University of Minho in Portugal.

### **Materials**

Eight sets comprised of three textile layers each were tested. The outer and intermediate layer were the same in all sets, varying only the inner layer, with the goal of improving users' comfort, as this will be the layer in contact with the patient's skin.

The composition, structure, and weight of both intermediate and outer layers are presented in Table 1.

Table 1 Textile composition, structure, and weight in the intermediate and outer layers.

Sample	Structure	Composition	Weight (g/m <sup>2</sup> )
Intermediate layer	Non woven	100% Poliester	35.28
Outer layer	Warp Knitting with PU coating	80% Poliester / 20% poliurethane	300.07

The inner layers varied in each set using both woven and knitting textile structures, as shown in Table 2.

Table 2 – Textile composition, structure, and weight of the inner layers.

Sample	Structure	Composition	Weight (g/m <sup>2</sup> )
1	Woven – plain	52% Cotton / 48% Poliamide	145,89
2	Woven – plain	52% Cotton / 48% Poliamide	104,52
3	Satin 5	52% Cotton / 48% Poliamide	151,08
4	Satin 5	100% Poliamide	127,54
5	Woven – plain	100% Cotton	116,20
6	Jersey	71% Polipropilene / 34% Poliamide / 5% Elasthane	217,66
7	Woven – plain	68% Cotton / 32% Poliamide	239,20
8	Woven – plain	100% Poliamide	164,73

## Equipment

All tests were conducted in an adiabatic chamber under controlled environmental conditions.

The thermal manikin used in this research, known as “Maria”, has the height and configuration of an adult woman, with the body divided into 20 independent thermal segments, where the dry heat transfer takes place in one direction, from the inside of the manikin to the environment. This electric model is heated throughout its surface to achieve a constant temperature, which can be adjusted to desired values, and to ensure a distribution of temperature across its surface similar to the human body. The power required to maintain constant temperature is measured and then correlated with the thermal comfort (Holmér, 2004).

## Method

Tests were conducted according to ISO 15831, and were carried out once the temperature of all manikin segments stabilized at 33 °C. The average room temperature was 22 °C, the relative humidity approximately 42%, and air velocity below 0.15 m/s. These parameters were monitored continuously throughout the test.

The manikin was placed lying down on a bed, static, thus simulating the position of a person on the operating table.

The textile sets were subjected to 3 tests for periods of 20 minutes each, and were placed on top of the manikin’s upper body, thus simulating a patient undergoing surgery in the lower body.

At the end of each evaluation results were automatically recorded and stored.

The thermal insulation of the tested materials can be calculated in two ways: by adding the area weighted local thermal insulation at the different body segments of the manikin - serial method - or by using the heat flow from the manikin’s body - parallel method (ISO 15831, 2004, Pamuk, Abreu & Öndoğan, 2008, Kuklane, Gao, Wang & Holmér 2012).

## Serial model — Surface area weighted thermal insulation

The total thermal insulation,  $I_t$ , or the resultant total thermal insulation,  $I_{tr}$ , is calculated on the test results gained with the manikin respectively either stationary or moving its legs and arms, using Equation:

$$I_t \text{ or } I_{tr} = \sum_i f_i \times \left[ \frac{(T_{si} - T_a) \times a_i}{H_{ci}} \right] (\text{°Km}^2/\text{W})$$

where  $f_i = \frac{a_i}{A}$

### Parallel model — Surface area averaged thermal insulation

The total thermal insulation,  $I_t$ , or the resultant total thermal insulation,  $I_{tr}$ , is calculated on the test results gained with the manikin respectively either stationary or moving its legs and arms, using equation:

$$I_t \text{ or } I_{tr} = \left[ \frac{(T_{si} - T_a) \times A}{H_c} \right] (\text{°Km}^2/\text{W})$$

where

$$T_s = \sum_i f_i \times T_{si} (\text{°C})$$

$$H_c = \sum_i H_{ci} (\text{W})$$

$I_t$  - total thermal insulation of the clothing ensemble with the manikin stationary, in square metre kelvins per watt;

$T_{si}$  - local surface temperature of section  $i$  of the manikin, in degrees Celsius;

$T_a$  - air temperature in degrees Celsius;

$a_i$  - surface area of section  $i$  of the manikin, in square metres;

$H_{ci}$  - local heat loss from section  $i$  of the manikin, in watts;

$A$  - total body surface area of the nude manikin, in square metres;

$H_c$  - heat loss from total surface area of the manikin's body;

$f_i$  - area factor of section  $i$  of the nude manikin

(Pamuk, Abreu & Öndoğan, 2008).

In this study, we used both methods.

In order to assess the thermal properties of the materials, previous tests were made with all the samples: outer layer, intermediate layer, and the eight potential inner layers.

Air permeability, tested in outer and intermediate layers, refers to the ability of a fabric to be traversed by air and is determined by measuring the speed of air flow passing perpendicularly through a test specimen under specified conditions. This measures the material's ability to allow air to pass through its pores or interstices (Soutinho, 2006). The evaluation of this property was undertaken according to the NP EN ISO 9237, using a pressure of 100 Pa and a test surface area of 20 cm<sup>2</sup>. The equipment used was the Textest FX 3300 Air Permeability Tester.

Thermal conductivity was tested in inner layers using the Alambeta apparatus, which makes an objective assessment of the hot / cold sensation. This feeling is important, not only in the moment one touches a fabric, but when wearing any piece of clothing or footwear, and during periodic contact of the inner parts of the garment with the skin (Soutinho, 2006).

## RESULTS

The results for air permeability of the outer and intermediate layers are presented in Figure 1.

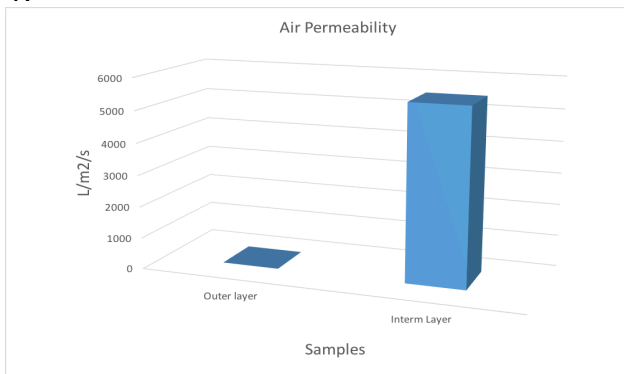


Figure 1 – Air Permeability of outer and intermediate layers

The air permeability of the outer layer is very low, whereas that of the intermediate layer is very high.

The thermal conductivity of the inner layers is presented in Figure 2.

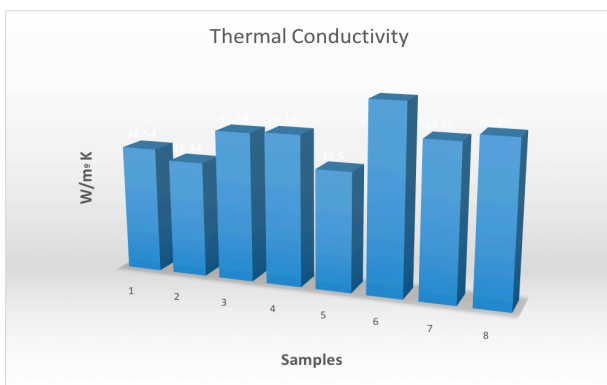


Figure 2 – Thermal conductivity of the inner layers

Thermal conductivity is highest for sample type 6, which indicates that this sample conducts more heat than the others.

Table 3 shows the results for thermal resistance (R) for all tested sets using both methods of calculation.

Table 3 - Thermal Resistance (R)		
R (m²K/W)		
Type	SERIAL	PARALLEL
1	0,409	0,213
2	0,441	0,219
3	0,416	0,213
4	0,494	0,235
5	0,369	0,201
6	0,546	0,242
7	0,445	0,22
8	0,384	0,205

Table 4 shows the results for the thermal insulation (clo) for all tested sets using both calculation methods.

Table 4 – Thermal Insulation (Clo)

Type	Clo	
	SERIAL	PARALLEL
1	2,639	1,374
2	2,845	1,412
3	2,684	1,374
4	3,187	1,516
5	2,38	1,296
6	3,522	1,561
7	2,935	1,419
8	2,477	1,322

These results show that the set type 6 reveals higher thermal resistance and insulation, using both models, serial and parallel.

## **DISCUSSION**

The results show that the set type 6 is the one with higher thermal resistance and greater insulating ability.

Both the intermediate layer and the outer layer were the same in all sets, whereas the inner layer was different in each set. These data make it clear that the inner layer was the determining factor for increasing the thermal insulation of the whole set.

Preliminary tests of thermal conductivity of the inner layers showed better results for layer number 6, which indicates that this may be an important feature of the inner layer performance.

The high results of air permeability of the intermediate layer and the low values of the outer layer show the importance of thermal comfort and the thermal insulation of the system we intend to build.

## **CONCLUSIONS**

The results of this study showed that, to improve the thermal body protection of the upper body of persons undergoing surgery in the lower body, the best performance in terms of their thermal insulation and thermal comfort capabilities was obtained with the 3 layers set produced with the inner layer number 6 (jersey knitting material with 71% Polipropilene, 34% Poliamide and 5% Elasthane). This indicates that its use may be more suitable and provide more effective thermal protection in patients during the perioperative period.

## **ACKNOWLEDGMENTS**

This work is financed by FEDER funds through the Competitive Factors Operational Program (COMPETE) and by national funds through FCT - Portuguese Foundation for

Science and Technology under the project UID/CTM/000264 and BD SFRH/BD/79762/2011.



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